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Gas Production Cross-Section Measurements at LANSCE: FY2002 Report

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Abstract

We are measuring the production cross sections for hydrogen and helium production by neutrons from threshold to 100 MeV on structural materials of importance to the Advanced Accelerator Application program. Our approach is to measure the isotopes of hydrogen and helium as they are emitted in the nuclear reactions such as (n,xp), (n,xd), and (n,xalpha). The data include not only the production cross sections but also the angular distributions and energy spectra of the emitted particles. These benchmark data also test nuclear reaction model calculations. Measurements have been made on iron in FY2002 and very preliminary results are discussed.

I. Introduction

The goal of this project is to measure hydrogen and helium production on structural materials proposed for the AAA program in the neutron energy range up to 100 MeV. At present there are few data above 20 MeV for such important elements as iron, chromium, nickel, and molybdenum. New evaluations that extend to higher energies (e.g. Ref. 1) are based to a great extent on nuclear model calculations. The data in these new evaluations, especially for the structural materials, invite tests and validation.

We have begun a program to measure these cross sections on elemental constituents of structural materials. This work is a continuation of measurements made up to 60 MeV on other materials such as silicon (Ref. 2) and cobalt (Ref. 3).

Our method is to detect protons, alpha particles and other isotopes of hydrogen and helium emitted in reactions induced by neutrons at the WNR/LANSCE spallation neutron source. Schematically, the measurement approach is shown in Fig. 1, where the correspondence of these microscopic measurements is made to the materials environment. Protons, deuterons, tritons, ^{3}He and alpha particles are emitted in reactions of the neutrons with the constituent elements of the material. In a component that is more than a few millimeters thick, most of these light charged particles stop in the material itself, although a few with high enough energy will exit the component and stop in neighboring material. For our experiments, we select thin foils of the material of interest so that all of the light charged particles can escape with little energy loss. We are thereby able to measure not only the production cross sections for the isotopes of hydrogen and helium, but also the energies of the emitted particles and their angular distributions. Although these latter two quantities do not affect the hydrogen and helium production, they are of importance in validating nuclear model calculations because they serve as further constraints on the models. With improved models, the production cross sections can be calculated with more confidence, and this is important for reactions that are difficult to measure in the laboratory.

Another important feature of our experiments is that the data are obtained for the full range of incident neutron energies simultaneously. Fig. 2 illustrates the technique. The WNR/LANSCE neutron source is a pulsed source based on short (sub 1 ns) bunches of 800 MeV protons that are incident on a tungsten neutron-production target. The resulting neutrons are collimated into small neutron beams, which then pass along flight paths to the experimental stations. For these measurements, we place samples 15 meters from the neutron source and use time-of-flight techniques to deduce the energy of the neutron that induced the reaction. As shown in the figure, the faster neutrons arrive at the sample first and are followed by lower energy neutrons.

From our previous work (Ref. 2), we show in Figs. 3 and 4 the type of data we expect to obtain. Spectra of alpha particles emitted from silicon are shown in Fig. 3 for four bins of incident neutron. The total production cross section for alpha particles is obtained by integrating the over the emitted energies. For silicon, the production cross section for alpha particles, which is very nearly the total helium production cross section, is shown in Fig. 4 over the range of incident neutron energies from threshold (about 6 MeV) to 60 MeV. Nuclear model calculations from the GNASH code are also shown in Fig. 3 and 4. In this case, the experimental validation of the calculations shows good agreement between the model calculations and the data.

II. Experimental setup

The test chamber is an evacuated chamber 55.9 cm in inside diameter to accommodate the test materials and the detectors. The apparatus is located on the 30-degree right beam line at the LANSCE/WNR spallation neutron source and is 15 meters from the neutron source. The chamber and the detector layout are shown in Fig. 5.

Detector systems for the emitted charged particles are deployed at 4 angles with respect to the incident neutron beam direction. The angles are chosen to cover much of the full angular range so that the angle-integrated production cross section can be reliably determined from the differential data. The detectors are coincidence counters consisting of (1)low-pressure gas proportional or silicon counters to identify particles as protons, deuterons, alpha particles, etc. followed by (2) silicon surface barrier detectors and (3) thick CsI(Tl) detectors to stop the most energetic hydrogen and helium nuclei. Signals from these detectors undergo preliminary processing near the chamber, and then the processed signals are transported to further electronics and a data acquisition system in a nearby area.

III. Progress to date

Earlier this year (January-March, 2002) we analyzed data taken in November and December, 2001. These data were to commission the detector station, shielding, detectors and the data acquisition system. For this commissioning, we used an iron sample and concentrated on the proton emission (hydrogen production) at several angles. Detection of protons from the target is challenging because protons are easily produced by neutron interactions with shielding materials. Typical data are shown in Fig. 6. A measure of the quality of data is the signal-to-background ratio. The signal-to-background ratio was found to be 6:1 in the forward angles and 3.5:1 at 90-degrees at E_n=100 MeV. At lower neutron energies, the signal to background ratios are significantly better. These results showed that the measurement program was possible. Some improvements in the collimation and shielding were indicated to make the measurement program even more solid, and we pursued them. The present signal-to-background ratios are significantly better than those found in the commissioning data.

Production runs started in the August, 2002. We have studied an iron sample by detecting charged particles emitted at 8 angles. We accomplished this by a relative minor design change that allows us to move the detector assemblies easily from one angle to another. More forward angles are accessible because of the significantly improved collimation of the beam. This more extensive angular coverage is necessary because of the more structured angular distribution at these higher neutron energies.

The data from these first production runs are being analyzed. Preliminary data for partial cross sections is shown in Figure 7, where the proton production above Ep = 14 MeV is given as a function of neutron energy. Lower energy protons were also detected and we will be able to give total proton production (which is most of the hydrogen production) when the data analysis is completed.

We made significant progress in increasing the staffing of this project. We hired a new postdoctoral fellow who joined our group in July, 2002. Two beginning graduate students helped us this summer to develop improved detectors and to improve the collimation of the neutron beam.

IV. Conclusions

The production cross sections for hydrogen and helium are being investigated up to 100 MeV incident neutron energy on structural materials of importance to the Advanced Accelerator Application program. Significant improvements have been achieved in the techniques so that more reliable data can be obtained. Partial and preliminary proton production data for neutrons on iron have been obtained in the incident neutron energy range up to 100 MeV. As the AAA program transitions into the Advanced Fuel Cycle Initiative, this measurement program will focus more on the lower neutron energy range although, with no extra effort, the higher neutron energies can also be investigated concurrently.

References:

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Gas production by neutrons in materials

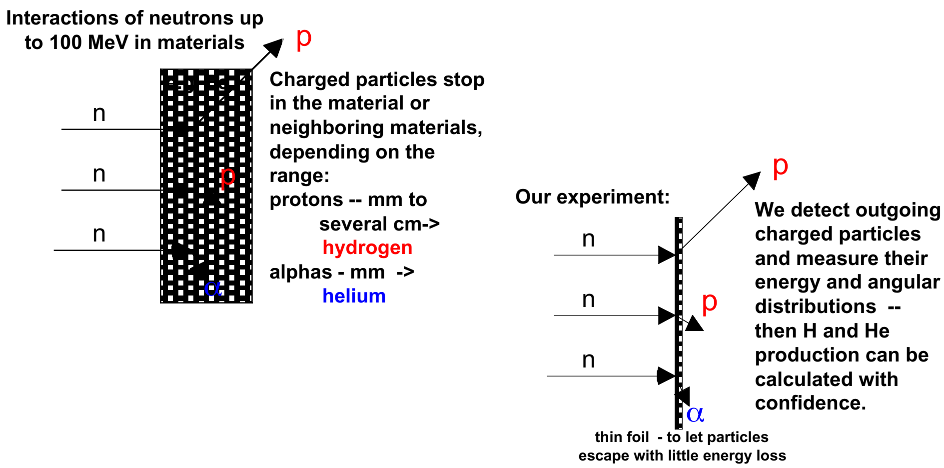

Figure 1 — Relationship of gas production in materials to our approach to measuring the production rate.

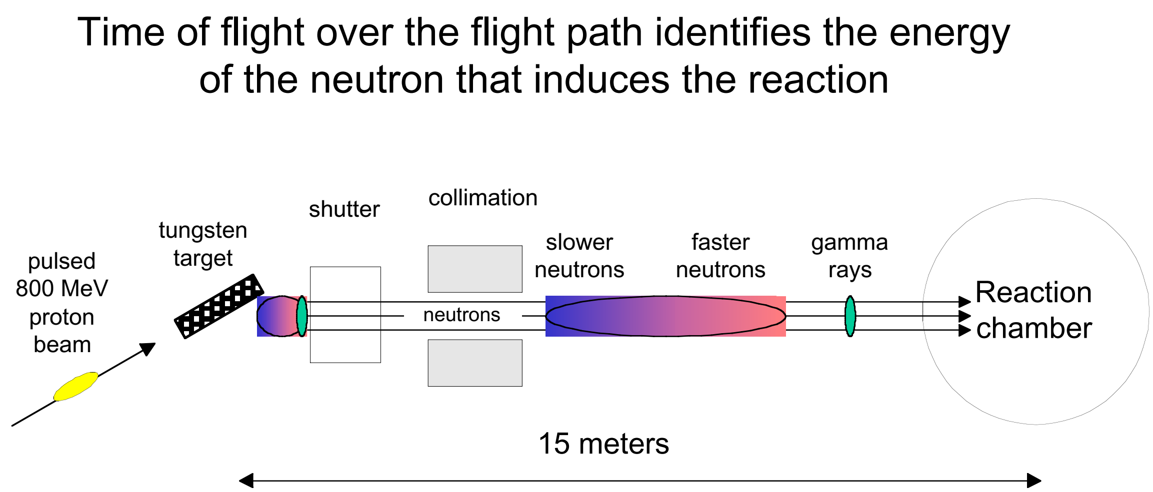

Figure 2- Time of flight technique: The incident proton beam is pulsed with a burst width of less than 1 ns. Neutrons, produced in the tungsten target by spallation reactions, are collimated into a neutron beam that travels 15 meters mostly through air before reaching the reaction chamber. Gamma rays from the source reach the reaction chamber first and are followed in turn by fast neutrons and then by the slower neutrons. The neutron time of flight is measured by a start timing pulse, derived from the proton beam and a stop pulse from detectors in the reaction chamber.

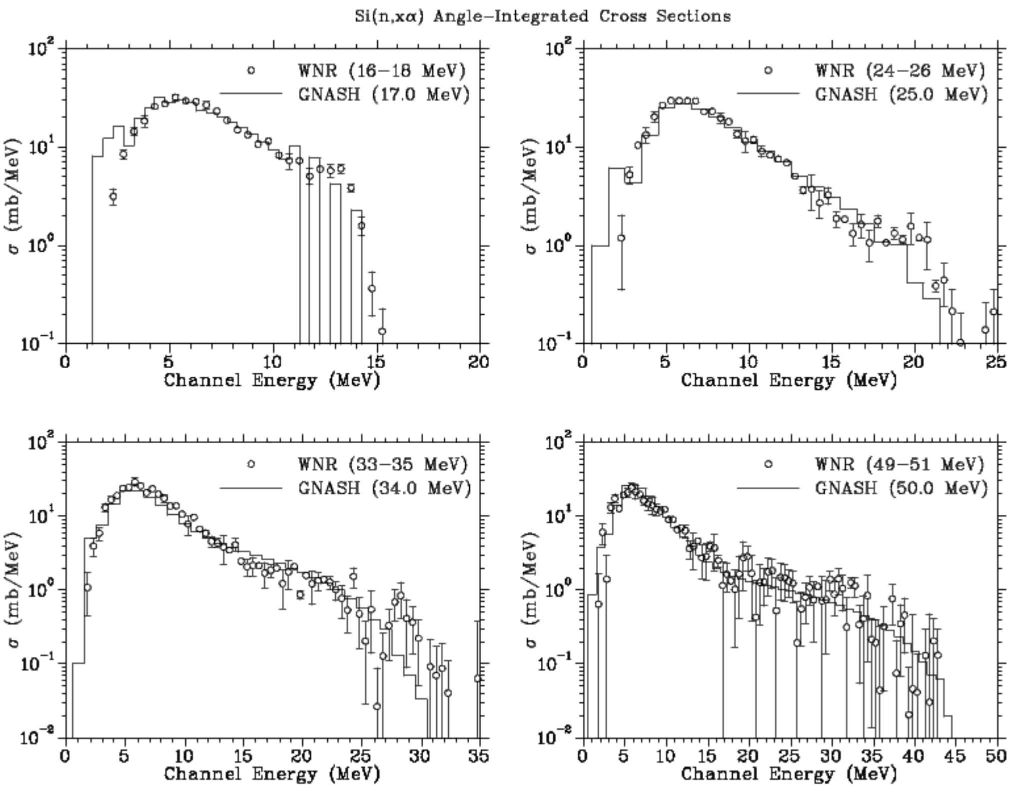

Figure 3 -- Spectra of alpha particles emitted from silicon bombarded by neutrons in four energy ranges. These data are integrated over the angle of emission. Nuclear model calculations (GNASH) are shown as the histogram lines. This figure is from Ref. 2.

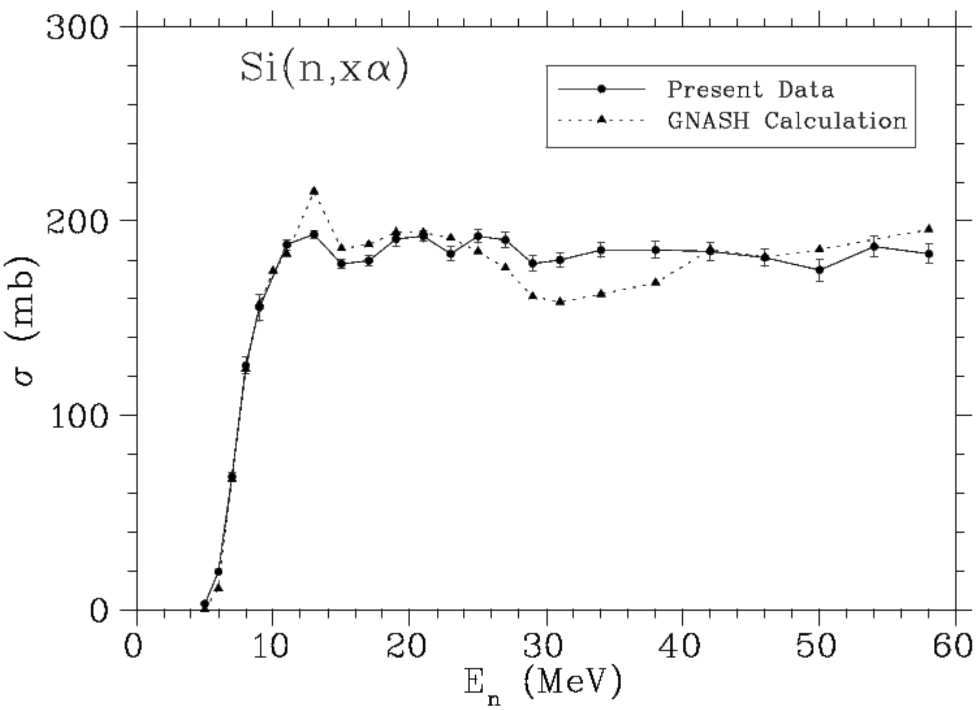

Figure 4 — Excitation function of the cross section for alpha-particle emission from silicon in neutron-induced reactions, from Ref. 2.

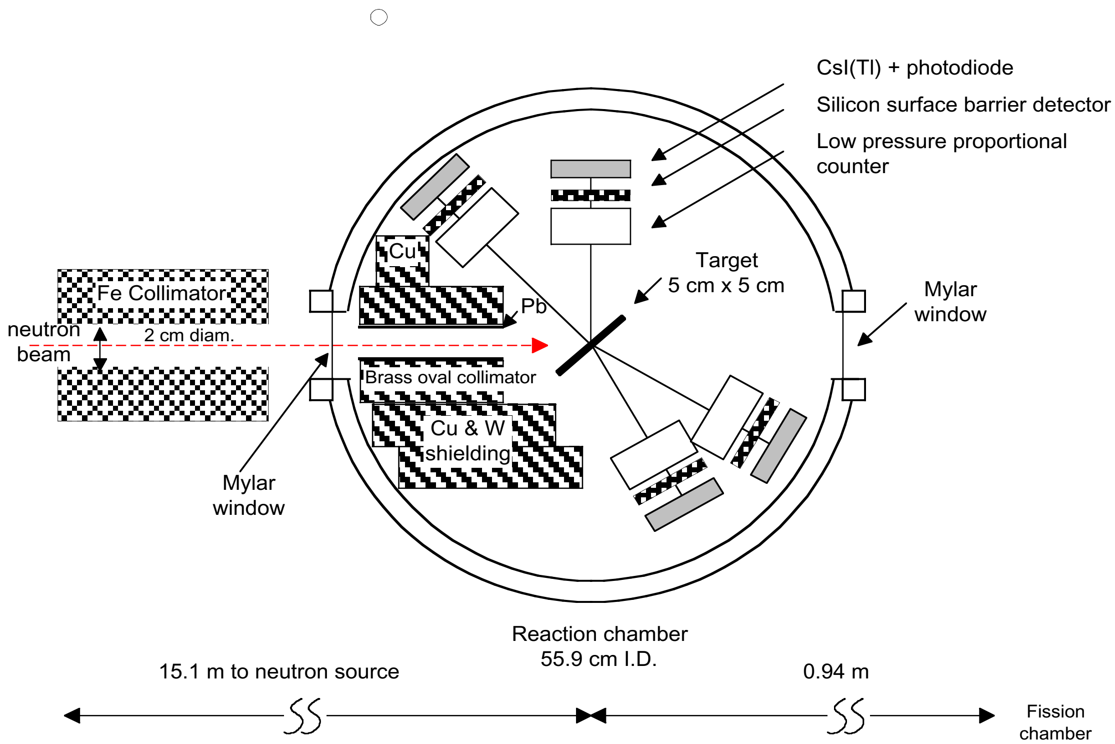

Figure 5 - Layout of apparatus for measuring neutron-induced hydrogen and helium production showing collimation for the neutron beam, target position, and array of detectors.

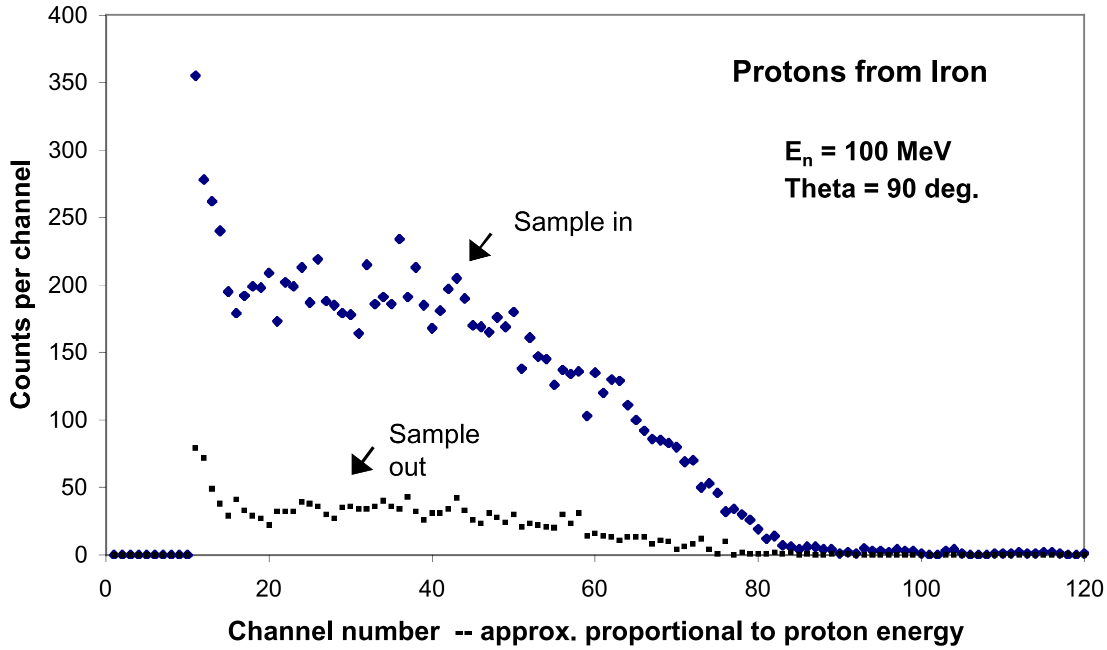

Figure 6 — Sample-in and sample-out measurements of proton production from an iron sample at a neutron energy of 100 MeV. The signal-to-background ratio is good at this neutron energy and significantly better at lower incident neutron energies. These data were taken before improved collimation and shielding were installed to reduce the sample-out background even further.

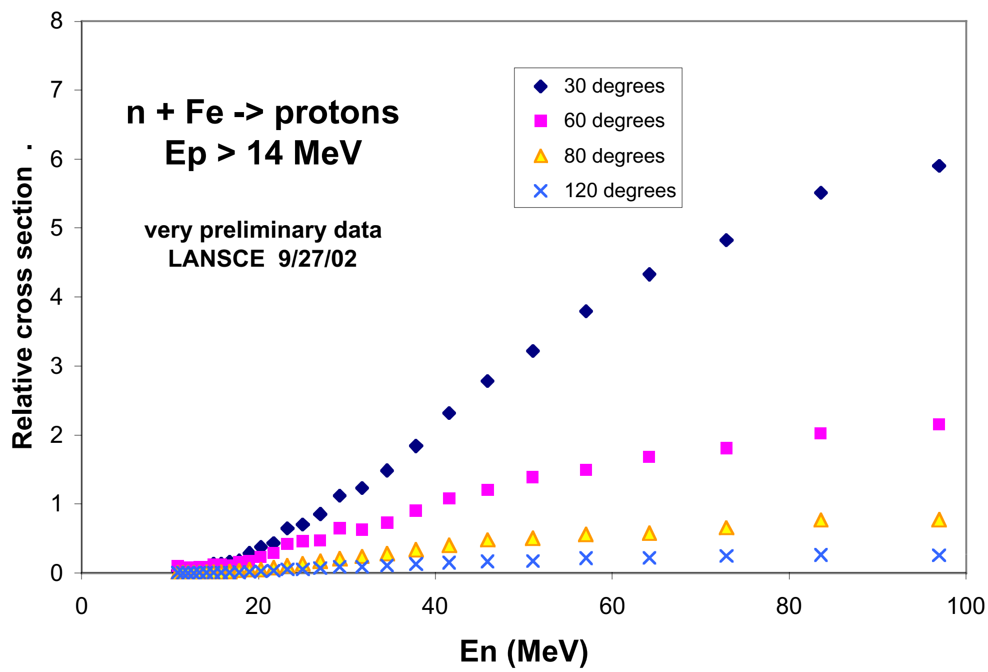

Figure 7 — Preliminary results from recent experiment of proton emission from neutron reactions with iron. The relative cross section for producing protons that have energies above 14 MeV by neutrons incident on iron is plotted for four of the observed angles and given as a function of incident neutron energy. The forward-angle production is clearly dominant and appears to grow monotonically with incident neutron energy.